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RESEARCH REPORT

OPTIMUM IDENTIFICATION CRITERIA
FOR AIR-TO-AIR ENGAGEMENTS

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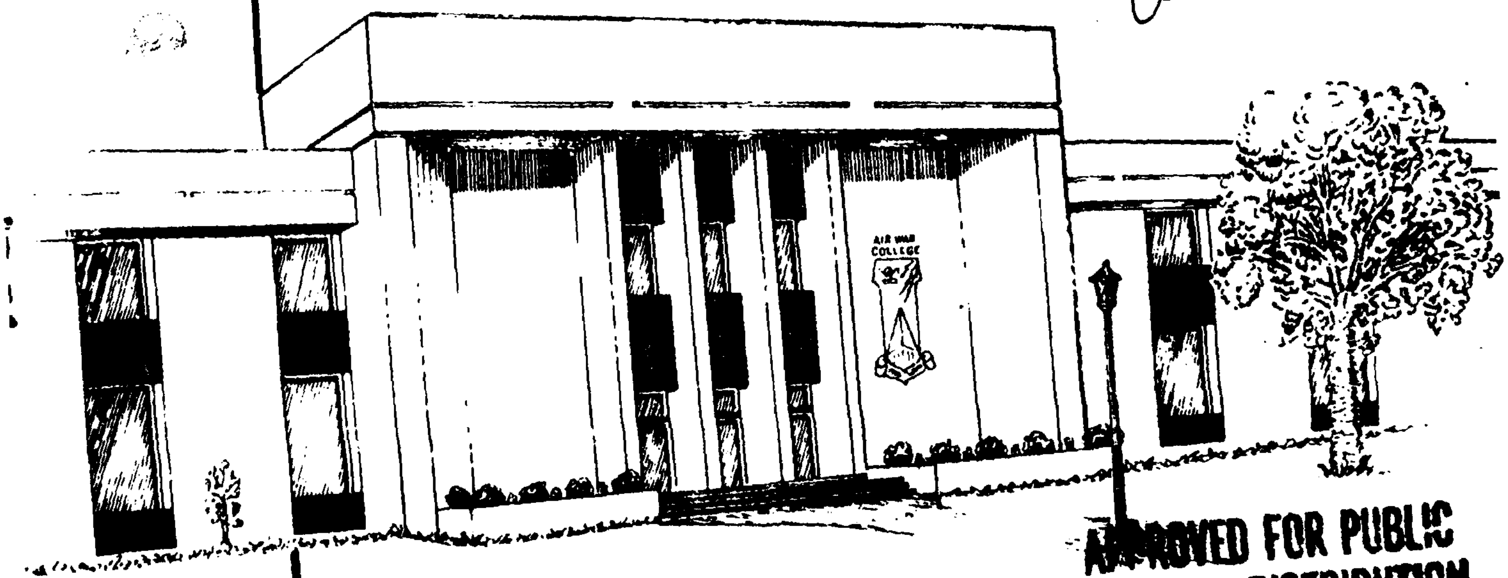
1989



AIR UNIVERSITY
UNITED STATES AIR FORCE
MAXWELL AIR FORCE BASE, ALABAMA

AIR WAR COLLEGE
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OPTIMUM IDENTIFICATION CRITERIA FOR AIR-TO-AIR ENGAGEMENTS

by

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Lt Col, USAF

A DEFENSE ANALYTICAL STUDY SUBMITTED TO THE FACULTY

IN

FULFILLMENT OF THE CURRICULUM

REQUIREMENT

Advisor: Colonel Melvin L Greene, Jr.

MAXWELL AIR FORCE BASE, ALABAMA

March 1989

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EXECUTIVE SUMMARY

TITLE: Optimum Identification Criteria For Air-To-Air Engagements

AUTHOR: James E. Neu, Lieutenant Colonel, USAF

The difficulties of identification (ID) of aircraft in combat are well known and documented.

This paper explains ID problems and the various technical solutions being considered or implemented by the USAF and NATO forces, and discusses the strengths and weaknesses of each. It then advances a method to mathematically combine the results of multiple ID systems in a suite for improved surety of ID. Finally, the paper models a generic four-system ID suite to examine the effects of increasing ID surety as a decision criterion for firing air-to-air missiles. The model simulates losses to enemy forces and to fratricide as a function of the ID surety required.

The results show that there is a breakpoint beyond which attempts to eliminate fratricide by requiring greater ID surety result in greatly increased losses to enemy forces. In addition, the data shows that overall losses are most sensitive to false reporting of friendly forces as enemy.

The author recommends further simulation with a force-on-force simulation model to better capture the incidence of the reporting errors which are known to exist with current ID systems. (KR)

BIOGRAPHICAL SKETCH

Lieutenant Colonel James E. Neu (M.S.B.A., Boston University, M.S.I.E., Stanford University) is a fighter pilot with operational experience in the F-4 and F-15 aircraft, including 200 missions in Southeast Asia and three years as an air liaison officer with the U.S. Army Airborne. During a Pentagon tour he served as an action officer for special projects under the Deputy Chief of Staff, Research and Development, Directorate of Requirements; and as the chief of fighter systems and deputy division chief of the Weapons Systems Liaison Division, Office of Legislative Liaison. He has studied information and warning systems in several contexts, and has published two papers on a reliability model for command and control of U.S. nuclear forces, and two on the effects of error rates on the value of automated cockpit warning systems.

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CHAPTER I

THE ENGAGEMENT

"Ranch 1 check!"; "Two": the F-15s checked in after completing their after refueling checklist somewhere above the skies of Denmark. Ranch one contacted the assigned NATO AWACS controller: "Blackjack, Ranch one and two, four radar, four heat each, with thirty minutes play time."

"Roger Ranch one, commit one two zero, 65 miles, unknown contacts, low." So this was it. Already into day three of hostilities, Ranch One and Two were committed immediately after their post-launch refueling. Ranch One maneuvered to a heading of 150° to offset the targets thirty degrees left on his radar. In a few seconds he had a contact. It checked out--low and fast, and headed for the peninsula. Now he saw other contacts well behind the first. His targets were probably on an air-to-air sweep ahead of the strike force--and they were definitely a threat to Ranch One and his wingman--<u>if</u> they were enemy. Their heading would take them through an area where the Danish Hawk batteries had been depleted the day before: "they must be enemy", he thought--"probably." Blackjack's commit call indicated she didn't know their identification (ID) either; he decided to press Blackjack just in case.

"Blackjack, Ranch one, contact one two zero, 50 miles, four thousand feet. We've got other contacts behind these. Confirm commit, or kill."

"Ranch one, Blackjack. Unable ID. Commit on lead targets".

"Ranch one, Roger. Committed one two zero, forty-six, four thousand" It sure would be nice to have an ID. Both Ranch One and Two carried four radar guided Sparrow and four heat-seeking Sidewinder missiles. The Sparrows could be launched before the targets could even be seen, and the Sidewinders before a positive visual ID could be made. It didn't help that the Navy had committed some air forces in the last two days. The F/A-18 looked for all the world like a Soviet Fulcrum--two tails, two engines, same size. Ranch one knew that every second of delay past the optimum Sparrow range was a second to be used by the enemy fighters to prepare their own attack--and their missile's range was roughly the same as his. They were at twenty miles, now. They sure seemed like enemy a/c, but Ranch One wanted to be sure; especially sure, since intell briefed this morning that two Danish F-16s were accidentally shot down yesterday by friendly fighters. All along the peninsula, Ranch One and his wingman, Blackjack, and the other fighters ready to back up Ranch One had the same question: "Who are those guys?"

CHAPTER II

THE PROBLEM

Fighter forces have come a long way since the days of World War II Luftwaffe Ace Major Erich Rudorffer, who explained his technique as: ". . .the best was when you dived with speed, made one pass, shot an opponent down quickly, and pulled back up. . . .The secret was to do the job in one pass; it could be from the side or from behind and I usually tried to open fire at about 150 feet." (1:9) Today's fighters carry long range, all weather missiles of considerable lethality. The Navy's Phoenix, carried on the F-14, can be launched in excess of sixty miles from the target. (2:204) The Air Force's new Advanced Medium Range Air to Air Missile (AMRAAM) is able to engage targets nearly twice as far away as the Sparrow mentioned above. The Army's Hawk and Patriot missiles, too, will shoot long before they have visually sighted an aircraft.

Until the fighter pilot or the Surface to Air Missile (SAM) operator is able to identify the target, however, these long-range weapons systems will be limited in employment, and therefore in effectiveness. Firing of weapons without identification can lead to fratricide, the loss of friendly forces. On the other hand, any enemy aircraft which is not identified and engaged early will have an opportunity to employ ordnance himself, again leading to the loss of friendly forces. Finally, AWACS and ground control sites rely on identification not only to direct attack against enemy fighters and bombers, but also to control and assist friendly fighters. Imagine the confusion if Ranch One gets vectors appropriate for Falcon Three One, who is on another mission altogether.

How real is the identification problem? According to a recent Defense Electronics article, "It is not only real, but profound. Serious air defense/threat identification problems exist in single-service, joint, and allied operations." (3:84) The problem of fratricide is more than an academic abstraction. In the 1973 Arab-Israeli conflict, the Egyptians apparently shot down 81 Israeli aircraft and 69 of their own. (4:80) During USAF exercise Copper Flag 84-3 there were five confirmed and four possible cases of fratricide. Most of these sorties were under ground radar control. (5:17) The Persian Gulf nightmare of 3 Jul 88, in which the Aegis cruiser Vincennes destroyed an Iranian Airbus with 290 passengers, was caused by the misidentification and subsequent engagement of the airliner. Reflecting concern about the state of combat identification, the FY 89 Defense Authorization Bill, passed by the Congress and signed into law by the President, directed the "Secretary of Defense [to] conduct a 'comprehensive fratricide assessment of US forces' from both air-to-air and surface-to-air weapons, including combat identification capabilities and force levels in 1990, 1995, and 2000." (6:30)

CHAPTER III

PURPOSE OF THE PAPER

This paper is directed to the dual problems of fratricide and the threat from an unidentified and therefore unengaged enemy aircraft. It seems obvious that the probability of fratricide will decrease as one insists on better identification before firing. However, if one assumes that better ID for a given ID suite implies a longer wait and a closer enemy (as in a positive visual ID) then it seems equally obvious that such a wait will increase the probability of loss of friendly aircraft to enemy action. There should exist, then, some level of identification confidence which will result in the fewest overall casualties (those from fratricide plus those due to enemy fighter action). This paper will offer a rudimentary model of the dual problems (friendly losses to fratricide, friendly losses to enemy action) and investigate the sensitivity of the "optimum" solution to some of the important variables in the problem. On the way I will describe the various classes of ID methods and show how inputs from two or more ID systems can be combined to provide a single, better identification.

CHAPTER IV

OTHER USAF STUDIES UNDERWAY

Two USAF Combat ID studies are presently underway. Each focuses on a specific portion of the ID problem, in greater depth than this study.

The first is an air-to-air Combat ID study conducted by the USAF Office of Studies and Analyses at the Pentagon. Its purpose is to ". . .evaluate the impact of restricting air-to-air missile employment to visual ranges due to uncertainties of identification and to quantify the value of ID systems in air-to-air combat." (7:1) The study uses the TAC BRAWLER air-to-air combat simulati^ , which allows force-on-force simulation of air-to-air combat. In the study, "Comparative evaluations were made on effectiveness in the few-versus-few engagement air battle environment, where F-15 fighter aircraft performed Defensive Counter Air (DCA) missions against the present day and 1995 air-to-air and air-to-surface Soviet aircraft threats." (7:1)

Figure one is a decision tree showing the Blue force options during the simulation. Either there were no restrictions, simulating a kill zone, or an ID was required. If an ID was required, then the next set of options was investigated. The "visual ID" (VID) case required either closure to visual range or observation of a positive hostile act.

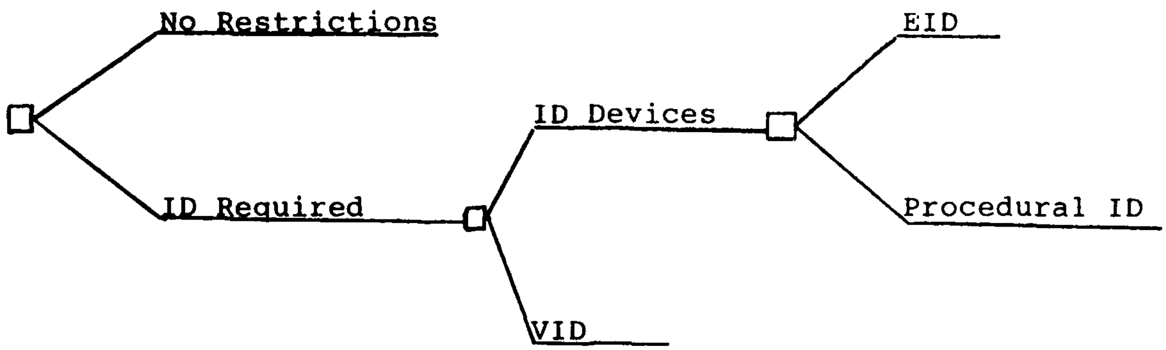


fig 1

In the "ID devices" case, both procedural ID and Electronic ID (EID) options were investigated. An aircraft which did not conform to required procedures was deemed hostile under the procedural ID rules and was always fired upon. The electronic ID option was simulated by a perfect ID device. Note that this simulation does not attempt to duplicate pilot behavior-- all targets located in a kill zone were engaged by the model regardless of the probability that a friendly aircraft might mistakenly enter the zone. Pilots may actually choose to forego that option to be sure of their target ID. Finally, note the model makes no allowances for ID system errors--they are all modeled as perfect systems, or for combining more than one system. (7:2)

The second study is Test Series Six conducted by the Identification Friend, Foe, or Neutral Joint Test Force (IFFNJTF) at Kirtland AFB, NM. The purpose of this test was to "Evaluate the identification performance of four autonomous F-15s performing the DCA mission in a simulated 1987 -

1990 Central European air war format." (8:1) This is a man-in-the-loop simulation, focusing on pilot behavior and performance given various ID options. The scenario

> "centered on a conventional conflict in the 4ATAF region of Central Europe. . . .The mission of the F-15s was to man defensive combat air patrols (CAPs) to maximize attrition of the Warsaw Pact (WP) adversary aircraft on offensive missions. F-15s were tasked to maintain CAPs in various forward and rear areas locations with wartime minimum-risk procedures and Rules of Engagement (ROE) in effect in accordance with COMAAFCE Supplan 35001M and COMFOURATAF Supplan 34001D. [The F-15s operated] in the autonomous mode [and] had no access to C^2 from higher echelons or to sources of indirect ID information. The pilots were required to rely on their on-board electronic devices or distinguish whether or not aircraft were in compliance with minimum risk procedures [or visually ID] to make ID and engagement decisions." (8:1)

Although kill removal of both red and blue forces was used in the simulation to enhance realism, kill data is not included in the data base "because this specific information is not a part of the IFFN charter which focuses on the identification process." (8:10)

This study does not attempt to duplicate either of the above studies. The analysis contained herein will assume imperfect ID systems, will combine multiple systems, and will include both fratricide and red kills on blue to determine an 'optimum' level of ID, and sensitivity to the variables contained in the model.

CHAPTER V

CLASSES OF IDENTIFICATION

Identification of aircraft can be provided to a weapons system by direct or indirect means. A direct identification is one in which the weapons system or its operator directly determines the aircraft ID with on-board systems. An indirect ID is one which is provided to the weapons system from another source. For example, if an F-15 aircraft interrogates the MK XII, mode IV, IFF system of an aircraft and determines it to be friendly, that is a direct ID. On the other hand, if AWACS determines the ID (by any means, including flight plan or point of origin) and advises the F-15 that his contact at a given bearing, range, and altitude is friendly, that is an indirect ID.

There are several classes of direct ID. First is procedural. In this case, procedures, such as preplanned return corridors or altitudes, are used to identify aircraft. In addition, rules of engagement (ROE) may establish certain behaviors as proof of identification. Also in this category could be the establishment of "kill zones", in which all aircraft are presumed hostile. (5:17) Next is cooperative ID. As the name implies, this class requires some cooperation from the unknown aircraft, such as a transponder response to an interrogation. Examples are the Mk X and Mk XII Identification Friend or Foe (IFF) systems currently employed by NATO aircraft, and the MK XV NATO IFF of the future. (9:91) The final class is noncooperative, usually termed noncooperative target recognition (NCTR) systems. In this case, no cooperation is required, so that an aircraft may not know that he is being identified, nor can he turn off an identification device. There are at least two types of NCTR technologies. The first relies on rapid computer analysis of radar returns. Computer systems of this type have been incorporated in the F/A-18, F-15, and F-16 aircraft (6:30) The second, which has been successfully demonstrated, passively detects radio frequency (RF) emissions from target aircraft and compares them with a table of known emissions. (6:30)

Influencing all types of ID is the question of friendly ID or enemy ID. A problem with friendly cooperative identification is that if the pilot or SAM operator fails to get a response, he does not know whether the target aircraft is a.) enemy, b.) friendly but with a failed or turned-off IFF, or c.) either, but his own IFF interrogator has failed. An operator would normally have greater confidence in a positive ID as enemy than he would in a lack of ID as friendly. Even the latter, however, does contribute to knowledge of a target's ID, as I will show in a later section.

Each ID system has unique advantages and disadvantages. Disadvantages of the cooperative system have already been alluded to--cooperation is required. Each NCTR system also has disadvantages. Radar-dependent systems, for example, are subject to jamming, while passive RF detectors require the enemy to emit (in this respect they share a limitation with the cooperative systems). Finally, all systems are subject to some confusion in correlation with the target to be attacked. For example, the IFF "window" (the volume of airspace defined by range error, elevation angle error, and azimuth angle error) may be 100 times greater than the corresponding radar "window" looking at a target. (see fig. 2) Thus a friendly aircraft in the vicinity of a target enemy aircraft may lend the friendly IFF response to the enemy radar return (10:41) Investigators believe this characteristic may have accounted for the Mode II (military) response which the Vincennes decoded from the Iranian Airbus. *The Mode II may have come* from a military C-130 preparing for takeoff behind the Airbus. (11:5) As Defense Science reported following the Vincennes incident: "Rather than argue about test results and capabilities of these alternative systems. . . .The most significant point is that no one system, the present radar/IFF included, fills the bill over the entire spectrum. . .but each of the 'alternate concepts' will perform very well in a particular sector of the environment or in certain situations, and will fall short in many other areas. What is generally not appreciated is that the special attribute of one of the 'alternate concepts,' which resolves the ambiguity of a critical identification situation, just might spell the difference between success or failure. (12:16) Figure 2 shows nominal "correlation windows" of two classes of ID systems, and graphically points out how the disadvantages of each can be overcome by the other.

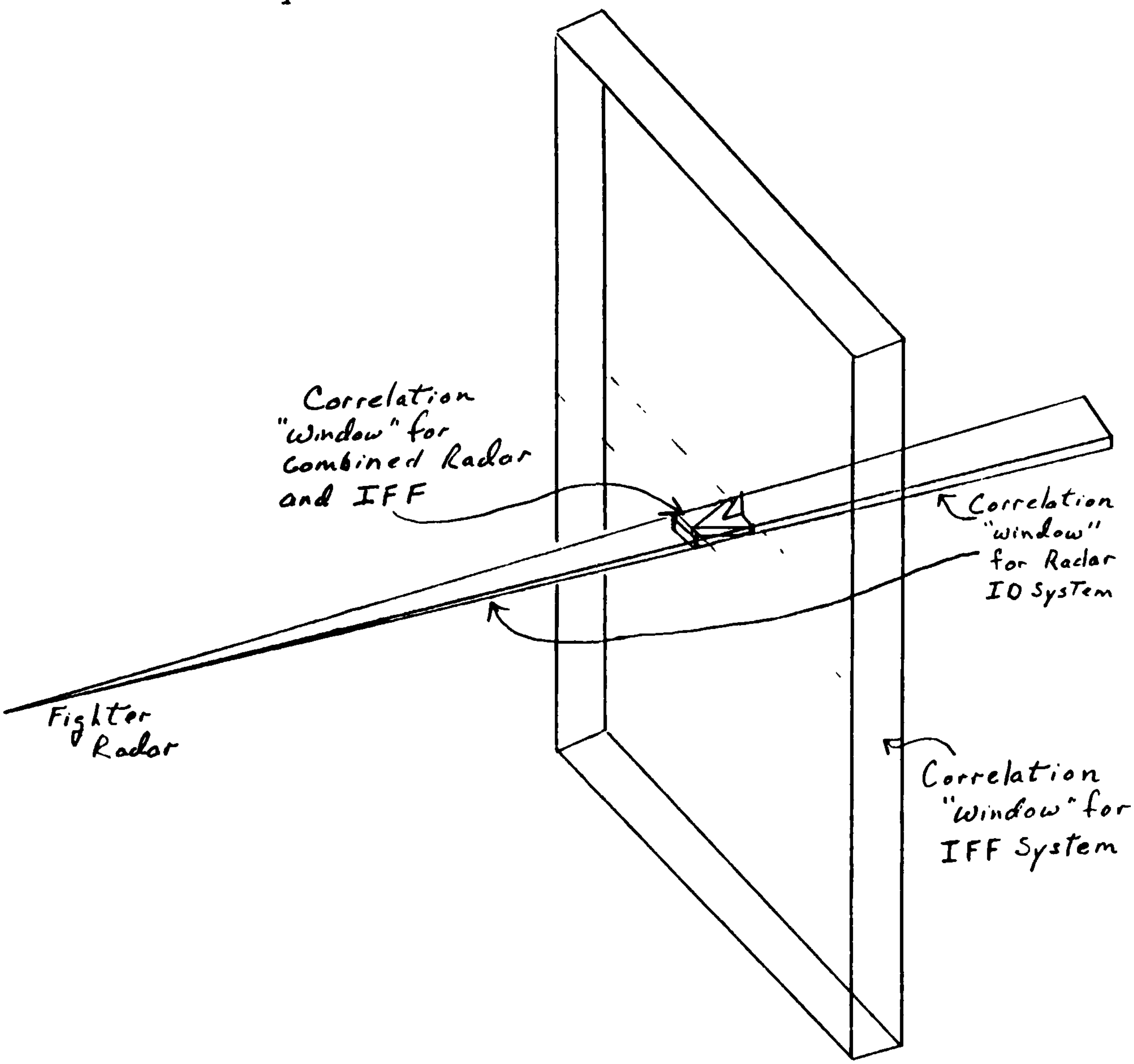


fig. 2

CHAPTER VI

MATHEMATICAL METHOD OF COMBINING ID INFORMATION

If each system has unique and independent strengths and weaknesses, how can we combine two or more systems, and what sort of improvement should we expect? The answer was developed by an 18th century clergyman-mathematician named Bayes, who developed a concept of probability which allows new information to influence a given probability assessment. Using his concept, any number of systems can be combined mathematically.

Let us assume that the expected ratio of friendly aircraft to enemy aircraft in a given theater on a given day is 6 enemy/4 friendly. In other words, there's a 60% chance that any target is enemy. But nearly any additional information would be useful. If the target is flying low and fast through a depleted Hawk belt, one might be more disposed to decide the target is enemy. Similarly, no response to an IFF interrogation is an indication that the target is enemy. But how much should we let those pieces of information influence our assessment of the target ID? How much confidence should we have in the indications? The answer lies in knowing the characteristics (reliability, accuracy) of the ID systems. To show how an ID report could be incorporated in the overall assessment of enemy ID, consider the following system, which we will call "system 1".

Probability that system 1 correctly identifies an enemy aircraft: P("E1"|E) = 0.9 (read "the probability [P] that system 1 reports "enemy" ["E1"] given [|] that the target is enemy [E] equals 0.9). Then the probability the system 1 reports an enemy as non-enemy (written as $\overline{\text{E}}$1) is: P("$\overline{\text{E}}$1"|E) = 1 - P("E1"|E) = 0.1.

Probability that system 1 mistakenly identifies a friendly (non-enemy) as enemy: P("E1"|$\overline{\text{E}}$) = .05.

In other words, given an enemy aircraft, this system correctly identifies it 90% of the time; 10% of the time it does not. Further, given a friendly aircraft, the system mistakenly IDs it as enemy 5% of the time; 95% of the time the system correctly reports a friendly aircraft.

The first error (failure to correctly report an enemy) is known as a type I error; the second (mistakenly reporting a friendly aircraft as enemy) is known as type II error, or false alert. Given this system, with known reliability and accuracy, and a report that the target is enemy, the updated probability that the target is enemy is given by Bayes' theorem:

$$P(E|\text{"E1"}) = \frac{P(\text{"E1"}|E) \times P(E)}{P(\text{"E1"}|E) \times P(E) + P(\text{"E1"}|\overline{E}) \times P(\overline{E})} \qquad (6.1)$$

In this case, with P(E) before the report = .6,

$$P(E|\text{"E1"}) = \frac{(.9) \times (.6)}{(.9) \times (.6) + (.05) \times (.4)} = .964$$

The new probability, after the report, is 96%. Notice that this result is most sensitive to the Type II error. The updated ID equation (6.1) can be written in terms of Type I and II errors as follows:

$$P(E|\text{"E"}) = \frac{(1\text{-Type I error})xP(E)}{(1\text{-Type I error})xP(E) + (\text{Type II error})x(1-P(E))} \quad (6.2)$$

Thus as the probability of the Type II error approaches zero, the updated probability given a report approaches 1.0. Conversely, a large Type II error will preclude high confidence in any ID report: for example, if the system reports friendly aircraft as enemy 30% of the time (a very high false alert rate), $P(\text{"E1"}|\bar{E}) = .3$, the result is $P(E|\text{"E1"}) = .81$, which is much less useful than $P(E|\text{"E1"}) = .964$.

The calculation of an updated ID probability after a report from an enemy ID systems, then, is straightforward. Friendly IFF systems require slightly different treatment. I pointed out in an earlier section that lack of an IFF response doesn't necessarily mean that a target is enemy. Does the lack of response, then, provide any useful information? It does, of course, but the relative weight of the information depends on the reliability of the systems. We can model the MK XV NATO IFF as follows: (numbers assigned are arbitrary)

> The probability of a positive IFF response [$\text{"}\bar{E}\text{"}$] ("not enemy") given the target is not enemy [$|\bar{E}$] is 70%. $P(\text{"}\bar{E}\text{"}|\bar{E}) = .7$. It follows, then, that the probability the system reports "unknown" ["U"] (no response) given the same friendly target, is $1 - .7 = .3$.
>
> Similarly, assume the probability of a positive IFF response given the target is enemy is just 5%. $P(\text{"}\bar{E}1\text{"}|E) = .05$. This could be the case where a friendly aircraft is in the same correlation window as the enemy target. Then $P(\text{"U"}|E) = .95$.

Now given the same initial force ratio of 60/40, a failure to respond to an IFF interrogation establishes the following new probability of "enemy".

$$P(E|"U") = \frac{P("U"|E) \times P(E)}{P("U"|E) \times P(E) + P("U"|\bar{E}) \times P(\bar{E})} \quad (6.3)$$

$$= \frac{.95 \times .6}{.95 \times .6 + .3 \times .4} = .826$$

Is reliability of an IFF system critical? What would be the result if throughout NATO each fighter correctly responded to an interrogation 97% of the time? Assuming the chance of correlation window error remains the same at 5%:

$$P(E|"U") = \frac{.95 \times .6}{.95 \times .6 + .03 \times .4} = .979$$

A much improved result.

Bayes' Theorem can be expanded to incorporate reports from several independent systems by the following expansion:

$$P(E|"E1","E2") =$$

$$\frac{P("E1"|E)xP("E2"|E)xP(E)}{P("E1"|E)xP("E2"|E)xP(E)+ P("E1"|\bar{E})xP("E2"|\bar{E})xP(\bar{E})} \quad (6.4)$$

As might be expected, the estimated ID after confirmation by two systems is quite good. Recall that with an initial estimate of P(E) = .6, system 1 gave us a new estimate P(E|"E1") = .964. If system 2 has the same accuracy and reliability of system 1, then:

$$P(E|\text{"E1"},\text{"E2"}) = \frac{.9 \times .9 \times .6}{.9 \times .9 \times .6 + .05 \times .05 \times .4} = .998$$

Three such independent systems would give:

$$P(E|\text{"E1"},\text{"E2"},\text{"E3"}) = .9999$$

In the same way, ID systems with other type I and type II errors can be combined, as can conflicting reports, to arrive at a calculated P(E|several ID reports). The question then becomes "When is enough enough?" Should a pilot put his flight at risk to gain visual ID on a target which is reported enemy by two systems but is not in a free fire zone? Should he engage an aircraft positively reported as enemy by an NCTR system but which also responds to friendly IFF interrogation?

CHAPTER VII

THE HYPOTHESIS OF AN "OPTIMUM" SURETY OF ID.

Since fratricide is a result of engaging misidentified targets, better ID implies fewer friendly losses to fratricide. If we graphically portray the probability of fratricide (which can be thought of as the expected number of cases of fratricide per 100 target contacts) versus the surety of ID required before shooting, we would expect the graph to generally decline as the required P(E|ID reports) increases.

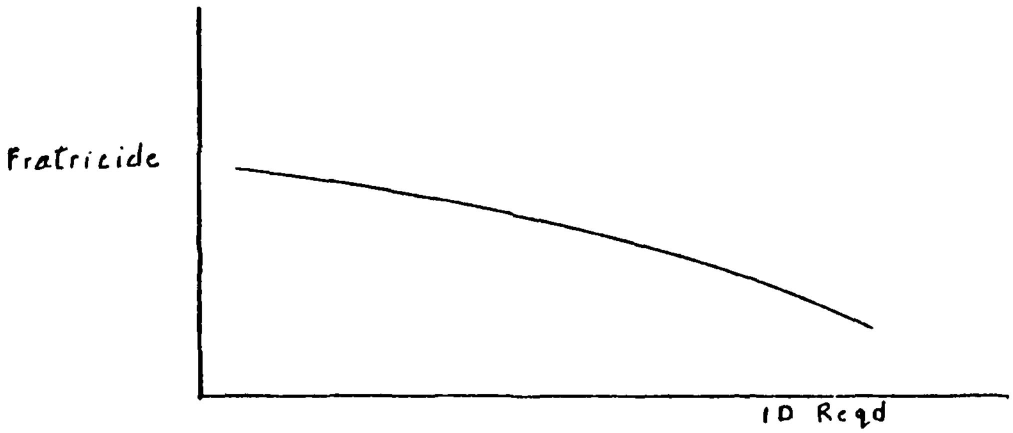


fig. 3

We might also assume that the chance of getting off the first shot declines as we strive for greater confidence in the ID solution. This implies a wait: that is, some ID will occur first (perhaps an indirect, or procedural ID); the second ID will occur some time later (For more information on this issue, see results of Test Series Six, reference 8). Certainly a visual ID requires a delay and close approach to the target. This delay, waiting for a second independent ID, or a third, and so on, implies an increased risk of losses to enemy fire. If we graphically portray the probability of loss to enemy actions versus the surety of ID required before firing, we would expect a graph of the following form:

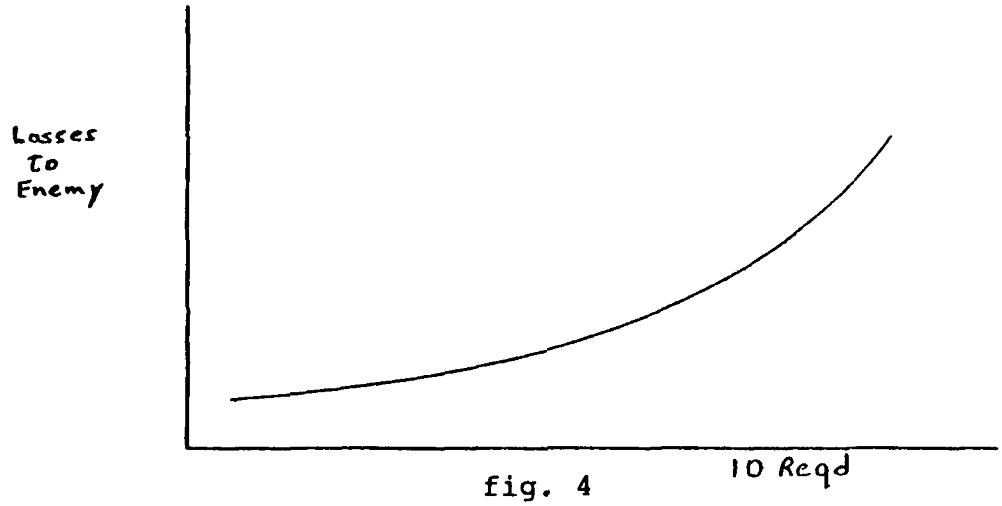


fig. 4

If we combine these two graphs to get a picture of total friendly force losses versus the number of IDs required to shoot, and plot the sum of the two expected loss rates, we should find some point at which the total number of friendly aircraft lost in battle is minimized:

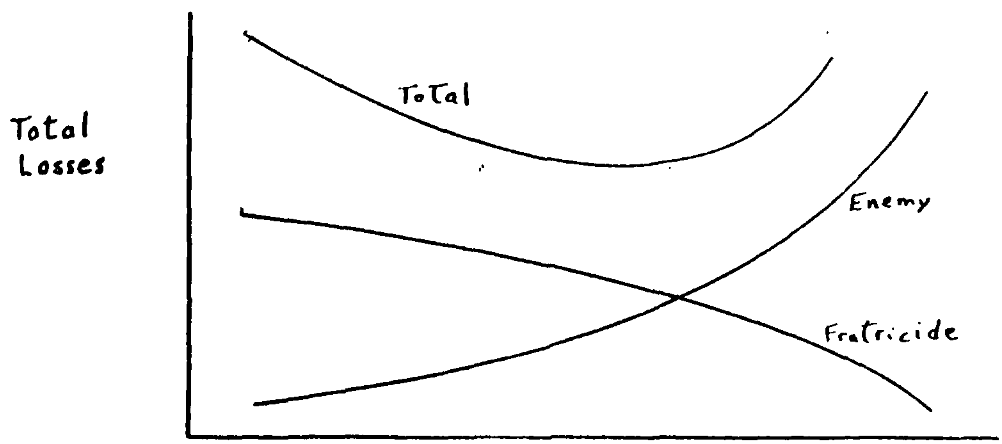


fig. 5

The hypothesis of this paper is: perfect ID, and therefore complete elimination of fratricide, is impossible; further, minimization of fratricide is not necessarily the proper goal. There should exist some level of ID surety, less than 100%, at which the expected total force loss is minimized. That solution will be sensitive to many variables, but some of these are known and others may be predicted on a mission-by-mission basis. The remainder of this paper will present a rudimentary method for such an analysis and an investigation into the sensitivity of the variables.

CHAPTER VIII

THE ANALYSIS METHOD

The model used for this paper consists of four generic ID systems. The pilot operates under rules of "shoot after you're sure of your ID to [the required] confidence." An example decision tree, with three ID systems instead of four for ease of explanation, is shown at figure 6. The symbols on the decision tree are defined as follows--note that quotation marks indicate a report of a condition, while symbols without the marks indicate the condition itself:

E	enemy
NE	not enemy (equivalent of $\bar{E}$)
"E1"	report of "enemy" by ID system number 1 (2,etc.)
"NE1"	report of "not enemy" (equivalent of "$\overline{E1}$")
"U"	report of "unknown" by IFF system (i.e., no report)
"0"	no report from the ID system
	decision point (where the pilot must decide between alternatives)
	chance point (where any one of several outcomes could happen, with the probability shown)
S	decision to shoot
ID	decision to ID with next system

The decision tree is read from left to right, and is shown from the pilot's perspective. His target ID is unknown. His first report is from an IFF system, which either does not respond (target is most likely enemy), or responds with a report that the target is not enemy. ("NE1"). Given no response ("U1"), the pilot must make a decision (□) to shoot (S) or to furtner investigate the target's ID (I) with

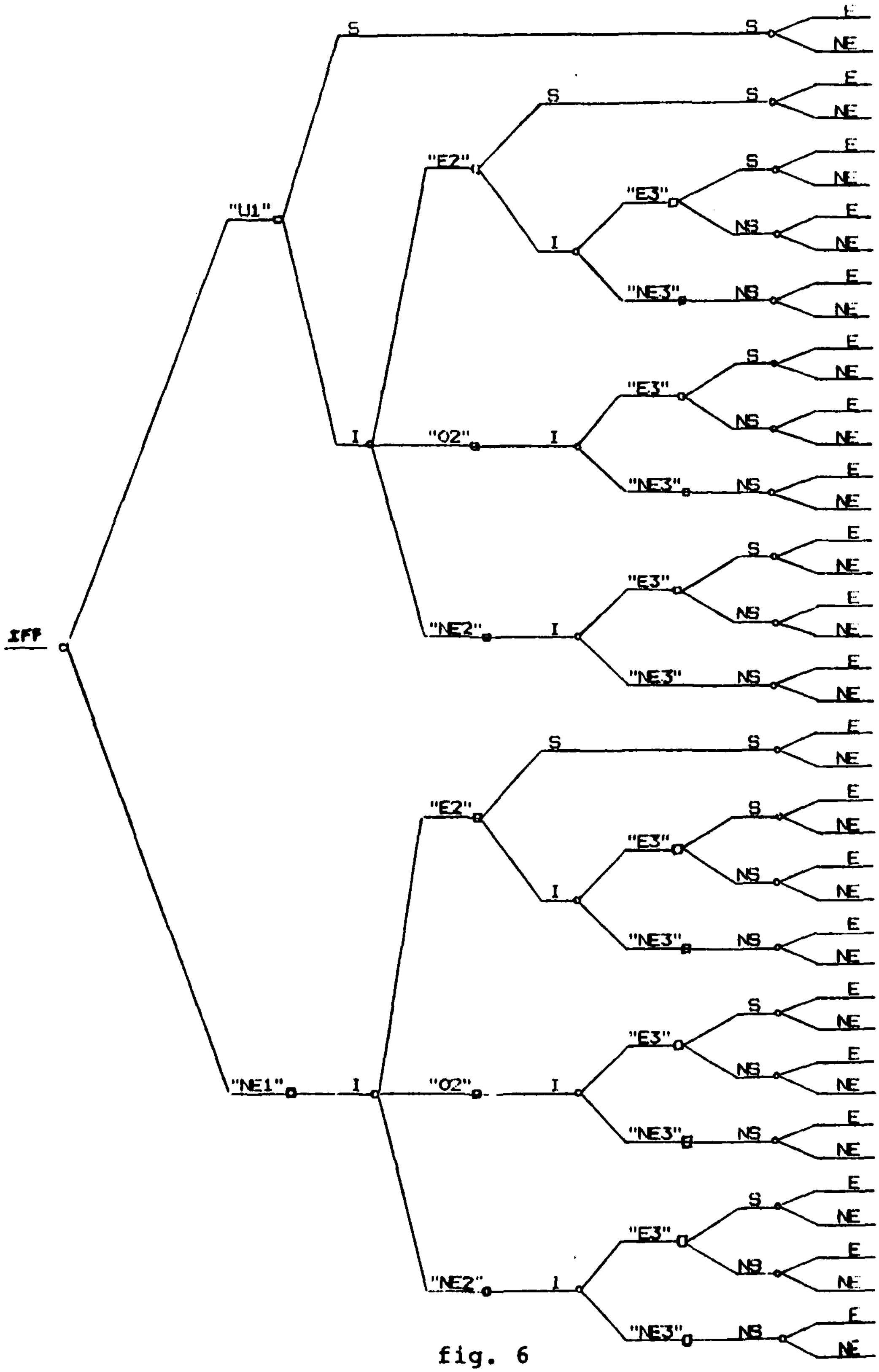


fig. 6

a second system. Assume the pilot needs more reports to meet his decision criterion. He elects to investigate further. System 2 reports "enemy" ("E2"), "friendly" ("NE2") or doesn't report ("02"). Whatever the report, the pilot must again decide to shoot or investigate further. In the cases where no additional information is available ("02") or where the report is friendly, the pilot's only choice (in this model) is to investigate. In all cases, after the pilot's decision: to shoot, or eventually to not shoot (NS), the actual identity of the target is determined by chance. A decision to shoot, with an outcome of 'not enemy' results in fratricide with probability Pkb (probability of kill for blue missile). conversely, a decision not to shoot, with an outcome of 'enemy' results in a blue loss to red action with probability Pkr.

The pilot's decision to shoot after a report of 'enemy' is based on the updated P(E) after the report. If the calculated P(E) after the report is greater than the ID surety required, he shoots; otherwise he investigates further (and flies closer to the target). The required ID surety may be reached via several paths. For example, reports of "U" and "E2" combined as shown in chapter VI will result in a high updated P(E). However, if system 2 did not respond ("02"), the same high criterion might be met by reports of "U", "02", and "E3". In this latter case the blue force pilot has met the firing criterion later, and is more at risk to enemy action.

The updated probabilities are calculated on a "flipped" decision tree which is the equivalent of the tree shown here but which is mapped from an observer perspective: the true ID of the target is determined by chance before the encounter takes place, and the ID systems then report the ID based on system characteristics. Appendix A contains one-half of the full tree used to calculate the updated probabilities and outcomes. That tree models four ID systems: An IFF system, which reports "U1" or "NE1"; two systems which report "E", "0", or "NE"; and a final system which simulates visual ID and reports only "E4" or "NE4". The two systems represent any systems which could report 'enemy', 'friendly', or not report, such as NCTR systems, indirect ID systems, or procedural ID. For the remainder of this report I will refer to them as NCTR systems.

I have used several important assumptions to simplify the model:

> All of the outcomes are based on multiple one-on-one passes, with all missile firings done before merging with an enemy aircraft.
>
> The pilot shoots at the first opportunity where the required ID criterion is met. In the case where the criterion is not met by the fourth attempt, he does not shoot.
>
> The ID systems are independent. That is, none of them is prone to the same error. The fact that one system mis-IDs a target does not alter the probabilities of correct ID of subsequent systems. Note that this is different from using the same ID system several times.
>
> The blue force pilot always gets the first shot if an ID occurs on the first attempt and the ID

criterion is met. After that, the chances of being the first aircraft to fire decline to a low of 40% if the criterion is not met until the last system reports.

There is a simple shot exchange model with Pk assigned to blue and red missiles. The shot exchange model allows for a three missile exchange: if blue's missile fails, red shoots; if that missile fails, blue shoots again. The model does not simulate missile fly-out. Most of the influence of missile differences is eliminated by calculating only the increased losses due to ID system performance. This is explained in greater detail in chapter IX.

The tree decision model (appendix A) is used as follows: selected P(E), Pk for blue and red missiles, and ID system Type I and II errors are inserted in the model. The updated P(E), expected blue losses to fratricide, and expected blue losses to red forces are calculated for every branch of the tree (every possible outcome). I then select an ID surety required to shoot (for example 85%), search the updated probabilities for those expected outcomes which would be forced by that decision rule, and sum the expected blue losses from each of those outcomes. This process is repeated for higher and higher ID surety criteria, and the expected blue losses to each case are then graphed along with a total expectation of losses. Expected losses with perfect ID information are subtracted from the result to isolate the effects of the ID process.

The following variables were investigated, singly or in combination, over the ranges indicated:

Initial probability of enemy, $P(E)$	.2--.8
IFF system Type I error, $1-P(\text{"U"}\mid E)$	.02--.2
NCTR systems Type I error, $P(\text{"}\bar{E}2\text{"}\mid E)$	.02--.2
IFF system Type II error, $P(\text{"U"}\mid \bar{E})$	.02--.3
NCTR systems Type II error, $P(\text{"E2"}\mid \bar{E})$	.02--.15

Appendix B is a table of the variable settings for each investigation.

CHAPTER IX

RESULTS

The baseline case selected included a target set with 80% of the targets enemy, Pk blue missile = 0.7, and Pk red missile = 0.6. ID system 1 models an IFF system, with P("U1"|E) = 0.9 and P("U1|$\bar{E}$) = 0.2. ID systems 2 and 3 model non-cooperative systems. Both systems report some result 70% of the time, both have a Type I error, P("$\bar{E}$"|E), of 10%, and both have a Type II error, P("E"|$\bar{E}$), of 5%. Finally, if the ID criterion is met with the report of the first system, the blue pilot shoots first 100% of the time. If the criterion is met by the report of the second system, he shoots first 80% of the time, and so on, with 60% at the third system, and only 40% when the ID criterion is not met until visual ID range.

In all the graphs that follow, the expected loss with perfect ID systems (losses due to a shot exchange with less than perfect missiles) is subtracted from the results, so that the graph represents additional loses due to the errors of the ID systems alone.

The results of the baseline simulation are shown in figure 7. Both the expected losses to fratricide and expected losses to red forces remain relatively constant until the ID criteria forces reliance on a second or subsequent ID system. The higher criterion causes a decrease in

LOSSES vs ID CONFIDENCE
BASELINE CASE

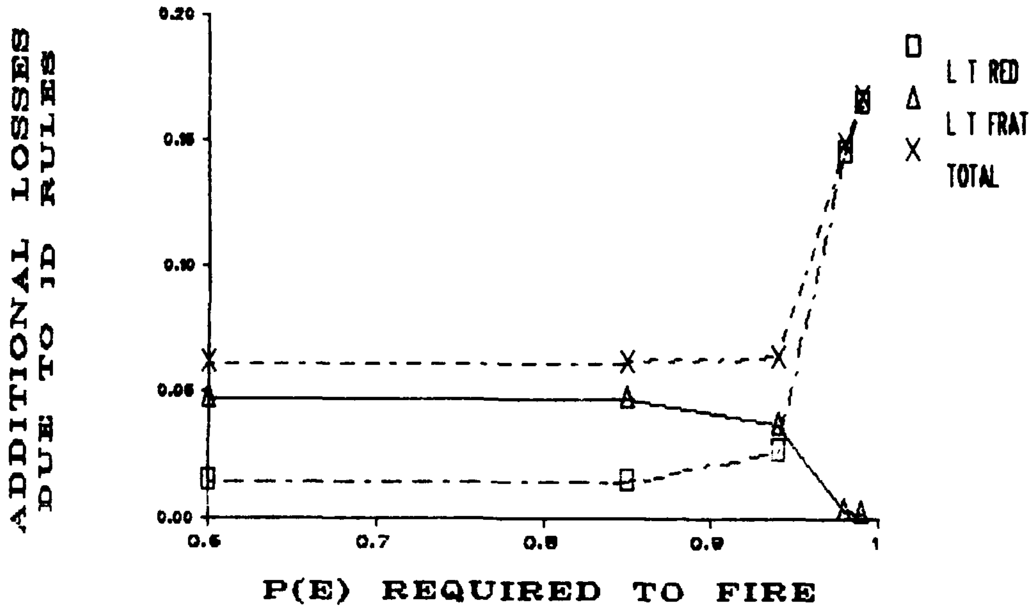


figure 7

fratricide, as anticipated, but with a very large increase in losses due to enemy forces. Given the characteristics of this baseline system, we would expect about a 6% loss of blue forces in many one-on-one engagements due to ID system performance alone. Fratricide could be reduced to less than 4%, but only at the cost of greatly increased losses to unengaged enemy fighters.

Figure 8 shows the results of improvements in both types of errors in the IFF system. Characteristics of systems 2 through 4 are unchanged. The Type I error, 1-P("U"|E), has been reduced to 5% from 10%, and the Type II error, P("U1"|$\bar{E}$), has been reduced from 20% to 5%. Ninety-five percent of the time this IFF system properly interrogates a friendly fighter and receives a correct response.

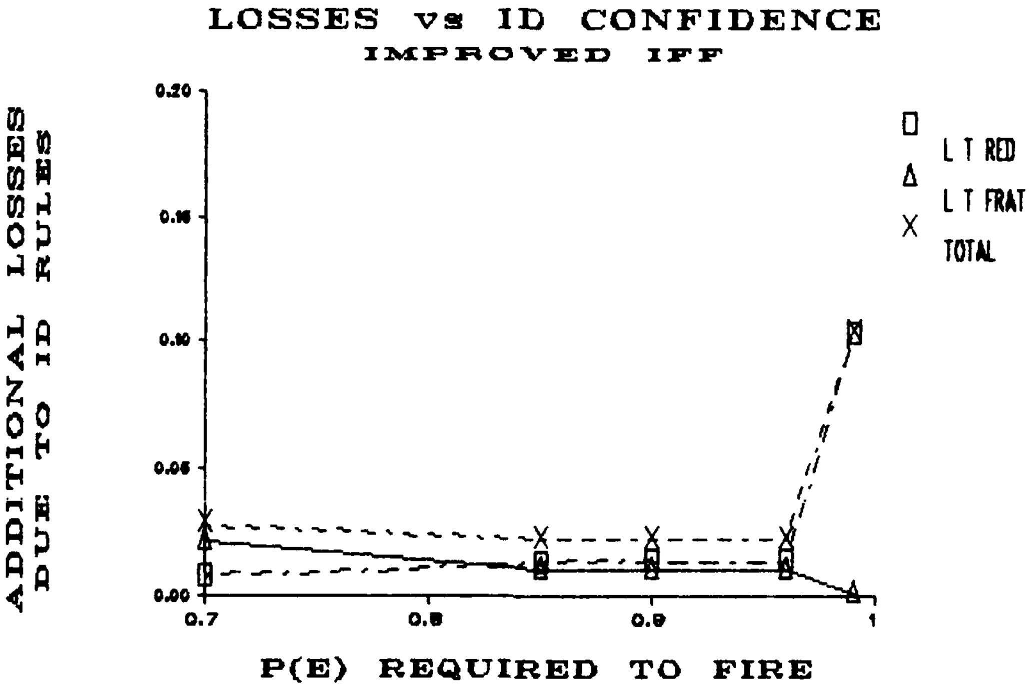


figure 8

In this case fratricide is driven to less than 1% if ID confidence required is greater than 85%, with very little increase in expected losses to enemy forces until the ID criterion is greater than 96%. Overall losses due to ID systems are minimized when the criteria are between 85% and 96% ID surety. These improved loss rates result from improvements in only the first of the four ID systems in the ID suite.

Figures 9 and 10 show the results of changes in both types of errors of the two NCTR systems. Figure 9 represents a case with errors worse that the baseline, while figure 10 shows a case better than baseline. In all cases, the

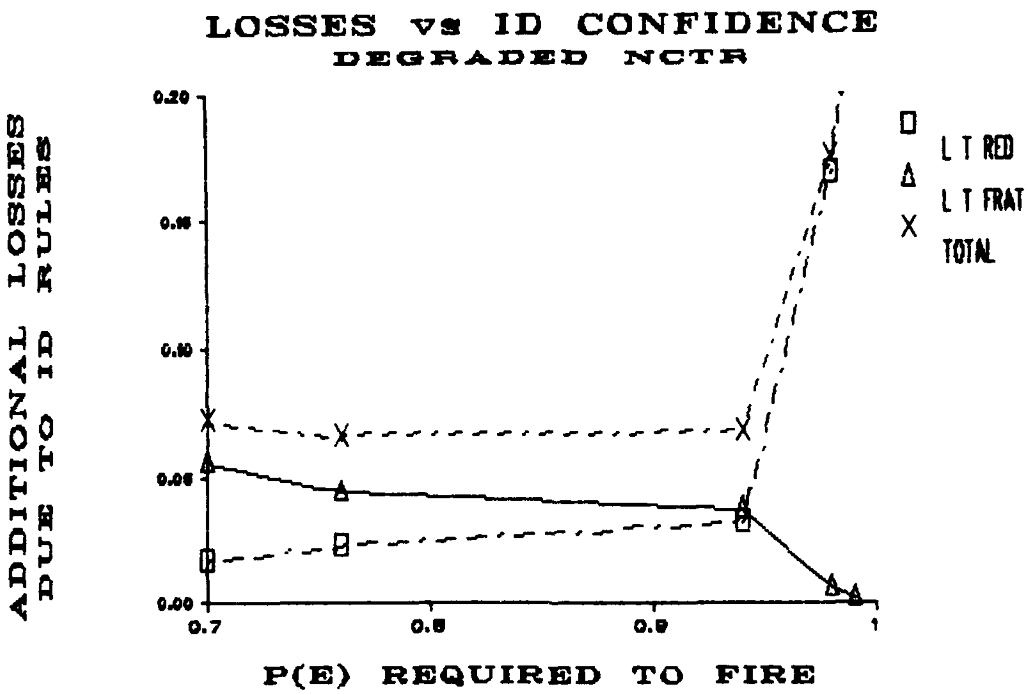


figure 9

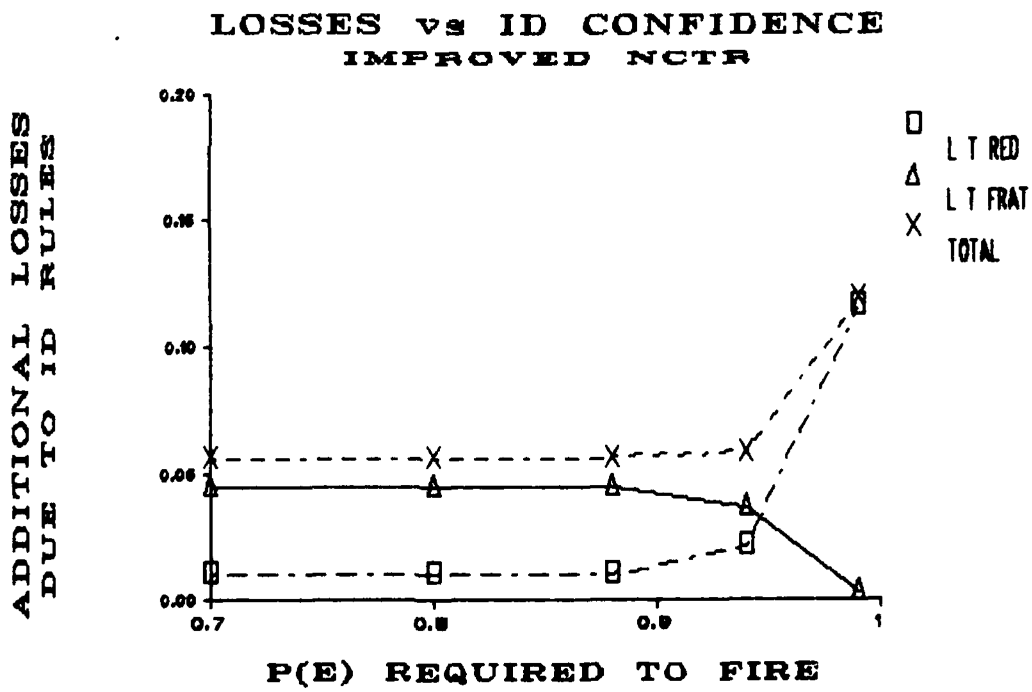


figure 10

probability of no response remains at 30%. The figures show only a slight improvement, which is caused by two factors. First, since the P(no response) = 30%, nearly one-third of the time the improvements in error rates have no effect.

Second, since there is a penalty for waiting for a report from system two or three, improvements here are again less effective.

Figures 11, 12, and 13 show the effects of changes on the Type I error (failure to report as enemy). For this set of comparisons and the next set I altered the assumption on penalty for waiting for a second or later ID. Here I assume that both system 1 (IFF) and system 2 provide reports at ranges such that the blue pilot can always shoot first if the ID criteria are met. A decision after ID system 3 has reported allows the pilot to shoot first 80% of the time (vs 60% of the time in previous figures.) The penalty for waiting until system 4 (visual range) remains the same: blue shoots first only 40% of the time. A comparison of figure 12 with figure 7 shows that this assumption has little effect on the results except when the ID confidence required exceeds 97%. However, this change will make the model more sensitive to changes in the accuracy of systems 2 and 3.

In figure 11 the Type I errors for systems 1,2, and 3 are 20% each. In figure 12 they are reduced to 10% each (same as the baseline case), and in figure 13 they are reduced to 2% each. Note that Type I errors can only occur when the target is enemy. Therefore improvements in these errors have very little effect on losses to fratricide, but do decrease losses to red forces and total losses.

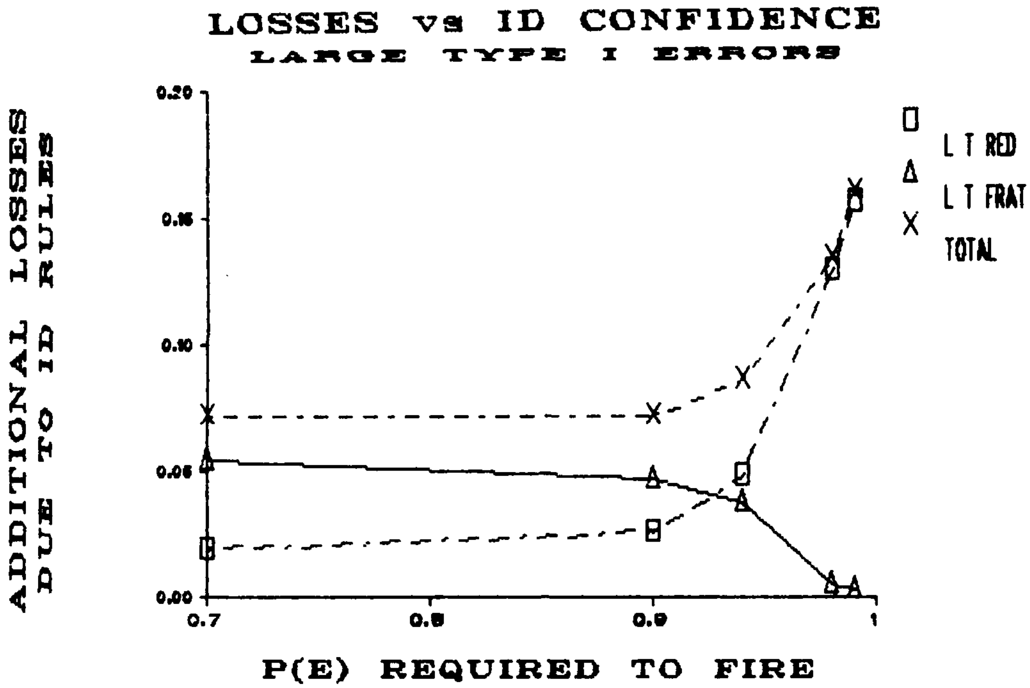


figure 11

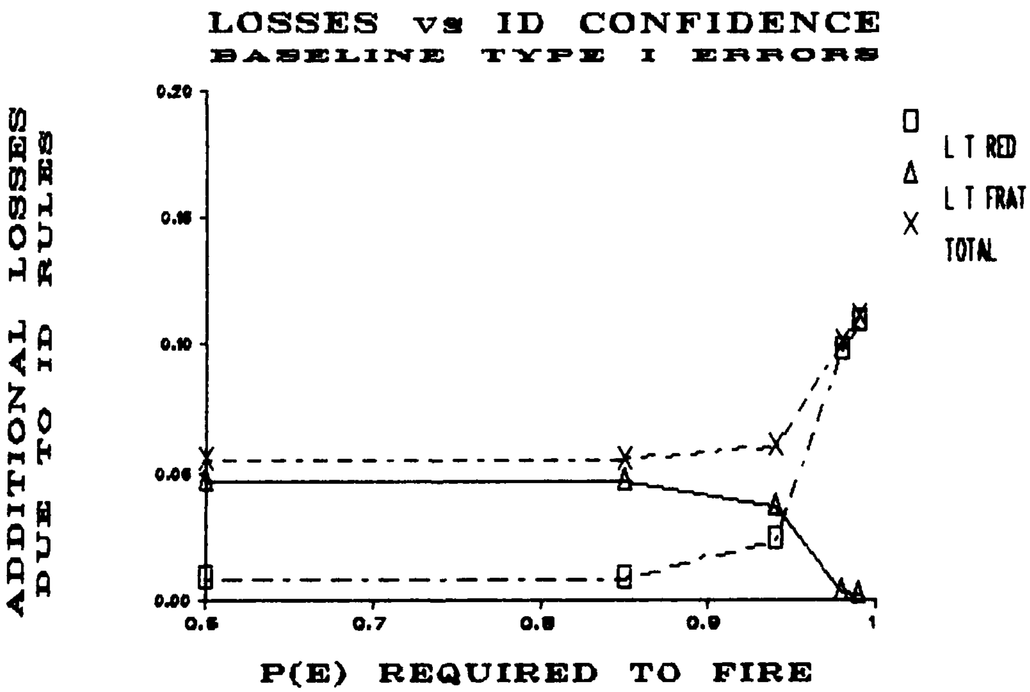


figure 12

Figure 13 shows that if Type I errors <u>in all three independent systems</u> could be reduced to 2%, then setting a very high ID surety criterion (99%) can reduce fratricide to near zero without the usual great penalty in losses to red forces. The minimum expected total losses, however, still occur at about 90% ID surety required.

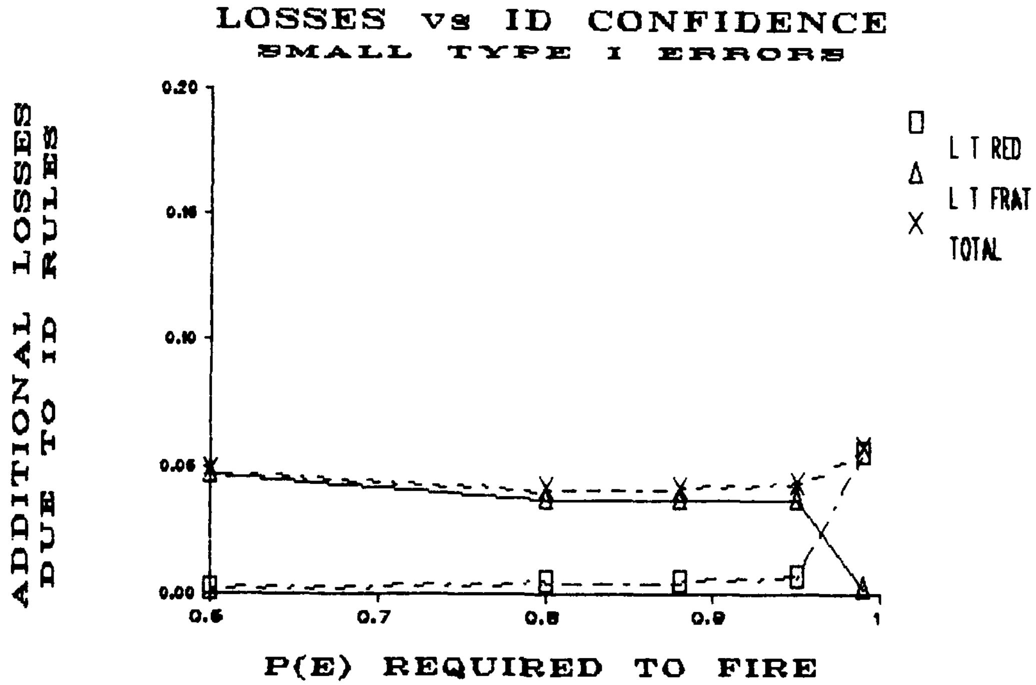


figure 13

Figures 14, 15, and 16 show the effects of changes in the Type II errors (false report of friendly as enemy). In figure 14 the Type II errors of systems 1, 2, and 3 are 30%, 15%, and 15% respectively. In figure 15 they are they are 20%, 5% and 5%, (same as the baseline case), and in figure 16 they are all reduced to 2%. Despite the fact that Type II error occur only when the target is friendly, changes in Type II errors effect both losses to fratricide and losses to red forces. This is because of the dramatic effect of Type II errors on the updated probability after an ID report (see equation 6.2 for further explanation). The differences between figures 14 and 16 shows the effectiveness of systems with low Type II errors. This would require reliability in an IFF system (correlation errors are not Type II errors in

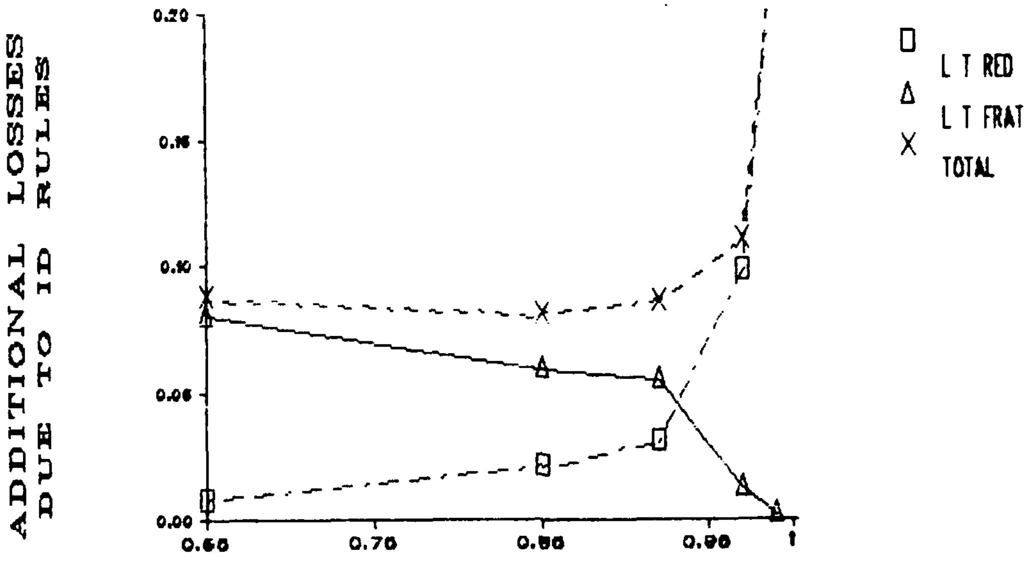


figure 14

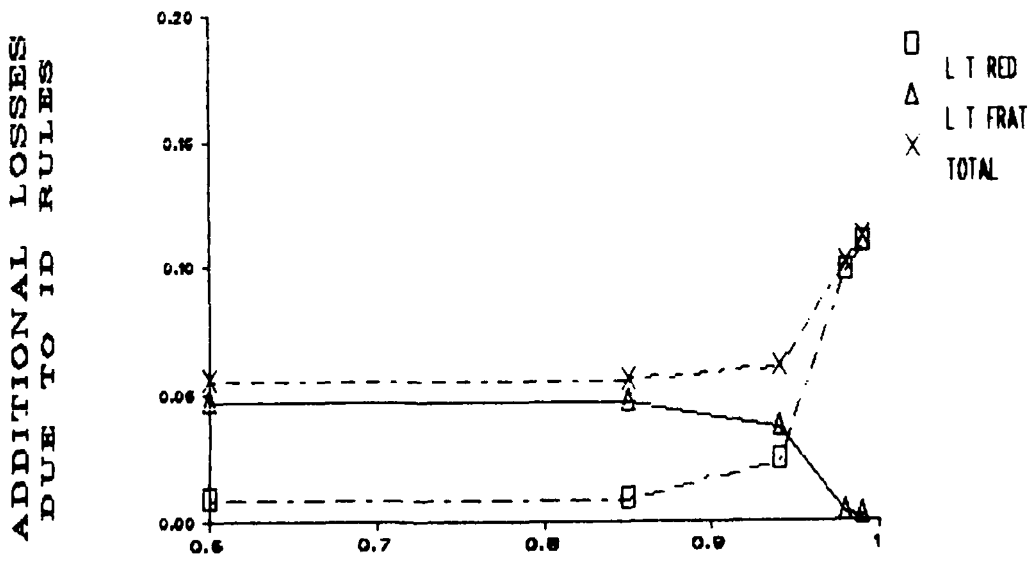


figure 15

a coded IFF system, only reliability of interrogation and response), and small correlation windows and ambiguity resolution for NCTR systems.

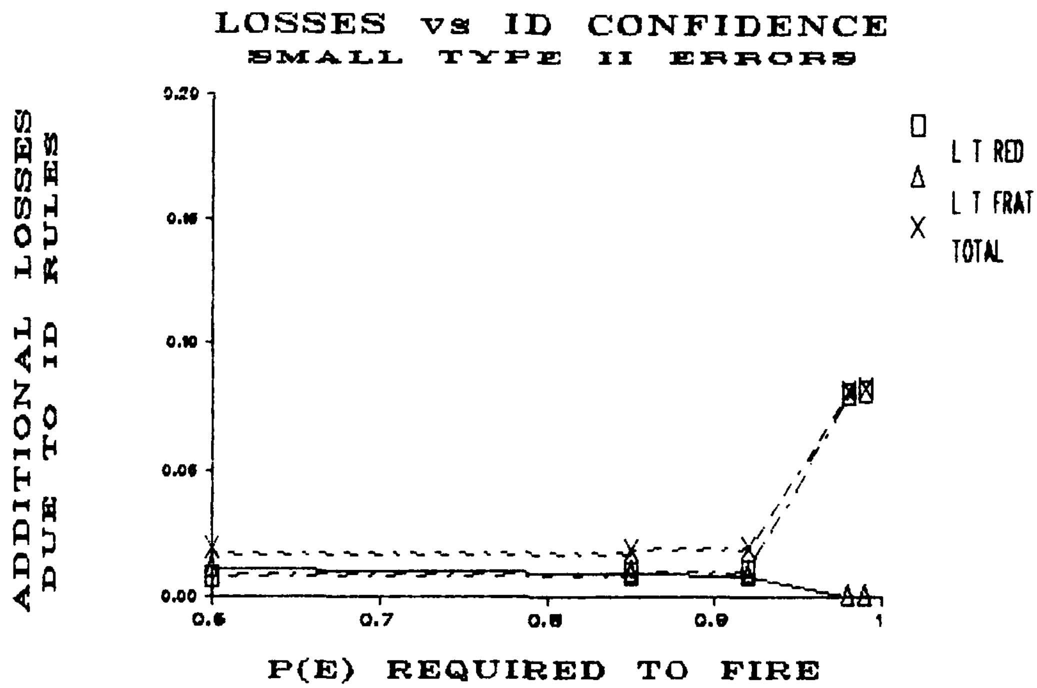


figure 16

Finally, figures 17, 18, and 19 show the effect of the underlying probability that a target is enemy. In figure 17 eight out of ten targets are friendly. Thus we see that a low ID confidence required to shoot results in a high incidence of fratricide, and fratricide quickly drops off as greater ID surety is required. In figure 18 one-half of the targets are enemy. This is the most stressful case for an ID suite, because there is greater uncertainty to resolve. A tradeoff between fratricide and loss to enemy forces occurs at about 85% ID surety required, with an overall minimum loss at about 90%. This case probably best shows the need for reliability and accuracy of ID systems, and the

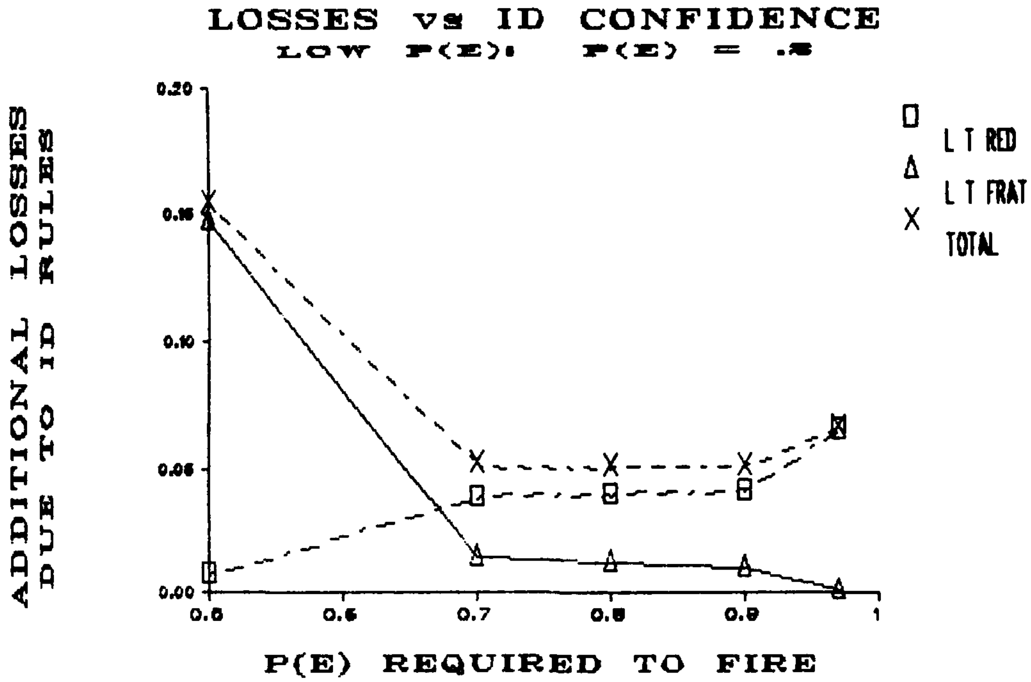


figure 17

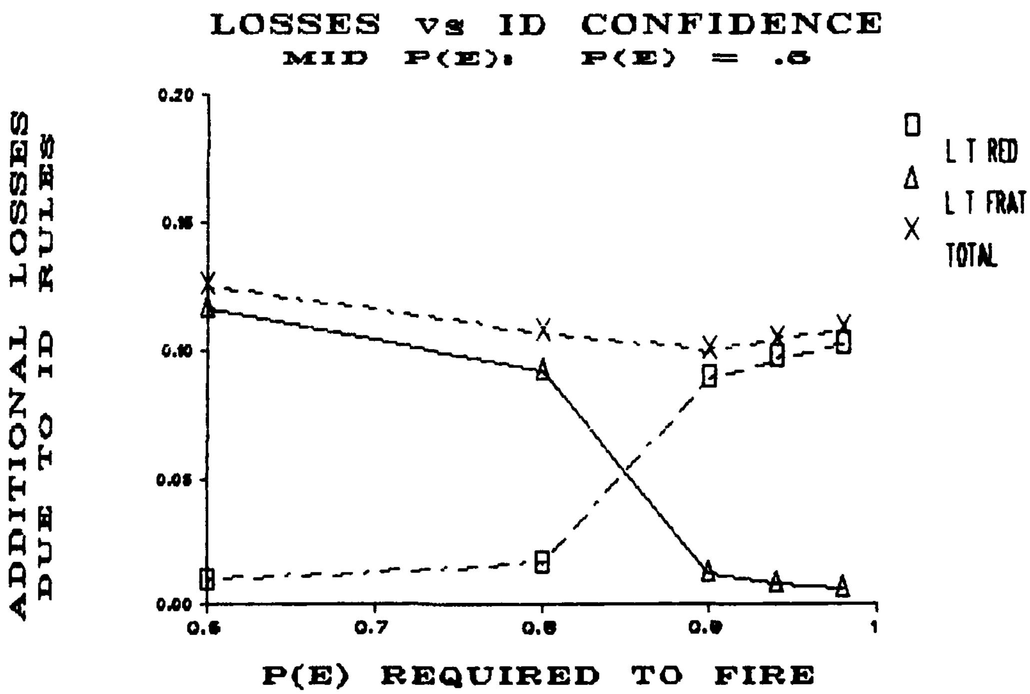


figure 18

need to combine the results of several system IDs. Figure 19 is the same as figure 3, the baseline case. The three figures taken together show that expected losses are sensitive to the initial assumed P(E), which would be based on the type of mission to be flown and on intelligence. However, for a given ID suite, such as the baseline case, the "optimum" decision criteria remains in the range of 85% to 95% regardless of the actual enemy and friendly mix encountered.

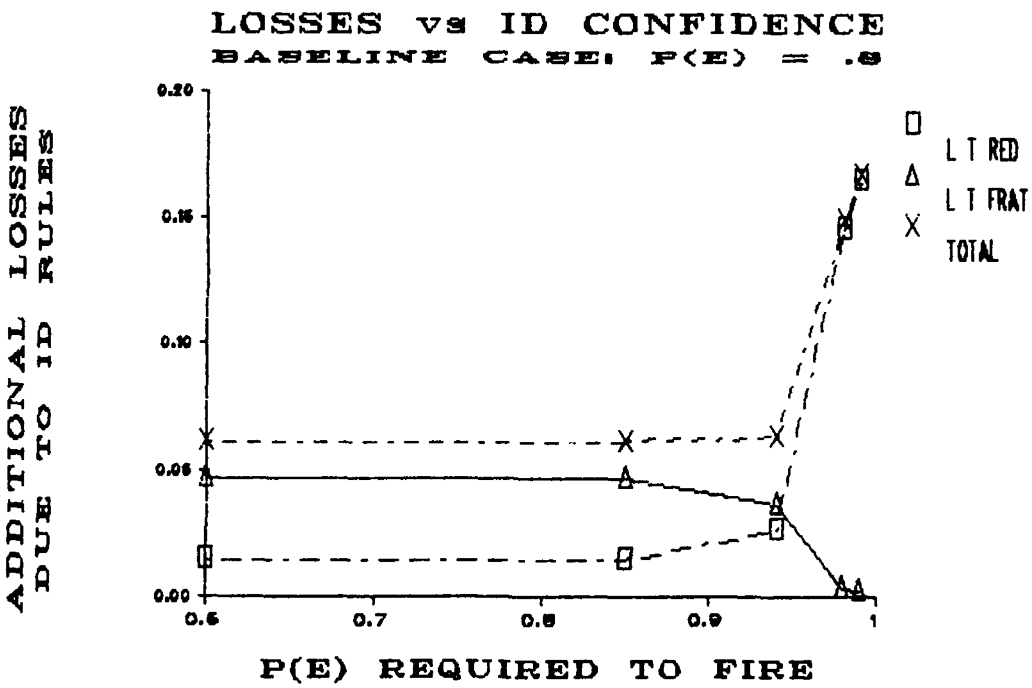


figure 18

CHAPTER X

CONCLUSIONS AND RECOMMENDATIONS

In order to draw accurate conclusions from the data presented here, we should first remember what the analysis does and what it does not do. The data presents expected outcomes of many one-vs-one air-to-air engagements fought entirely with missiles fired before the fighter-target merge. The outcomes are determined by the accuracy of target ID and the decision criteria, under the assumption that there is a penalty for delaying a decision to shoot in order to get improved ID surety. The effects of missile Pk, situation awareness, tactics, defensive maneuvers, countermeasures, and pilot skill, have not been modeled. However, given any combination of the above factors, the incremental effects of good or bad ID should be consistent with the results presented here.

Conclusions:

1.) for a given ID suite losses due to fratricide decrease as greater ID surety is required. Similarly, losses to enemy forces increase;

2.) there is a break point where the losses to enemy action due to the ID criteria far outweigh any gains in reduction of fratricide. This break point occurs at about 97% ID surety required;

3.) losses to both fratricide and enemy action are reduced as the reliability and accuracy of the independent ID systems are improved; and,

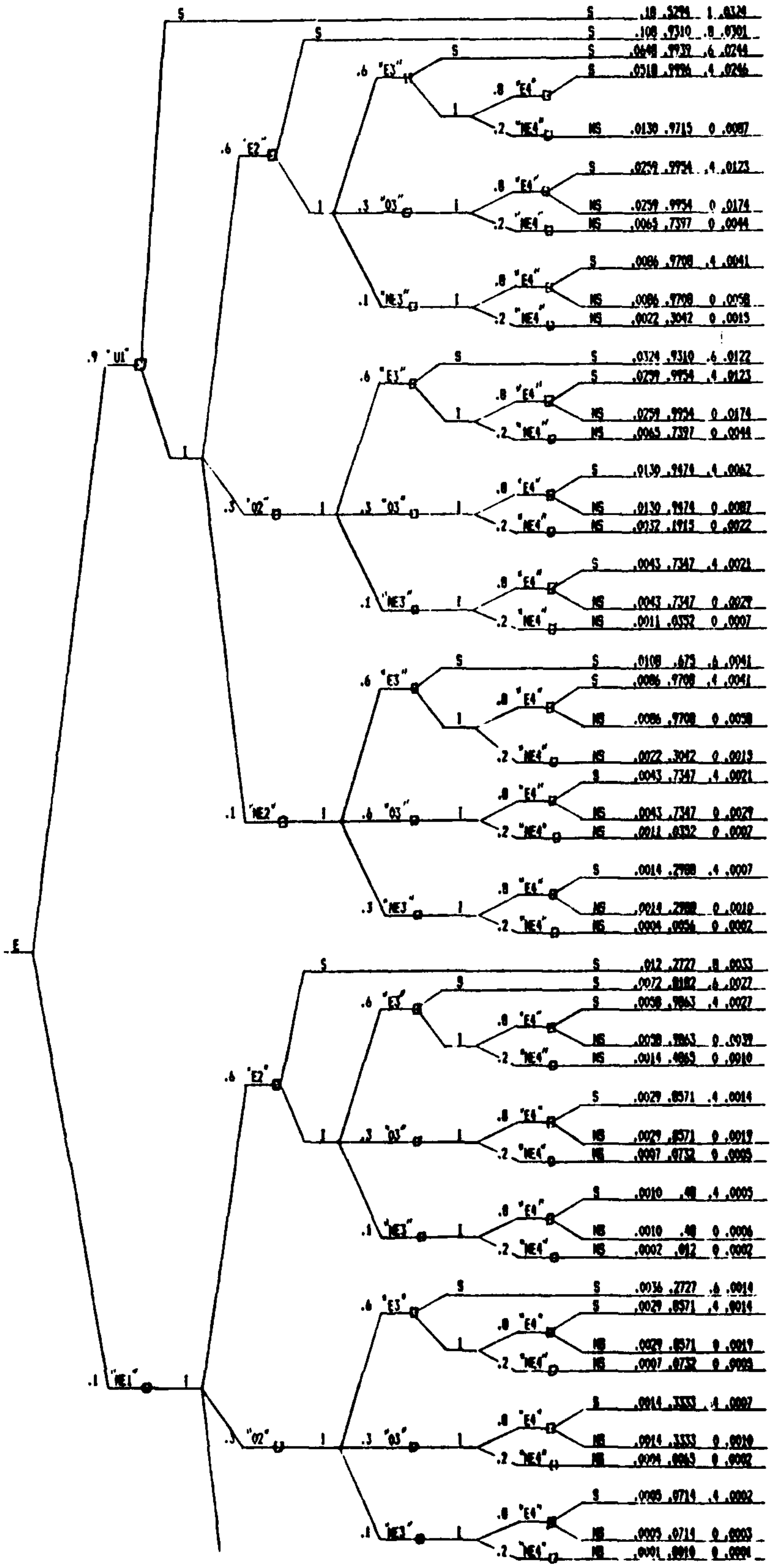
4.) Type II errors in ID systems are most costly, with both fratricide and losses to enemy forces showing sensitivity to changes in that category of errors.

5.) Any friendly aircraft which is not equipped with a common IFF contributes to the Type II error of the IFF system. This would indicate that if all of NATO is not committed to field a new IFF system at nearly the same time, the new system will be of little value.

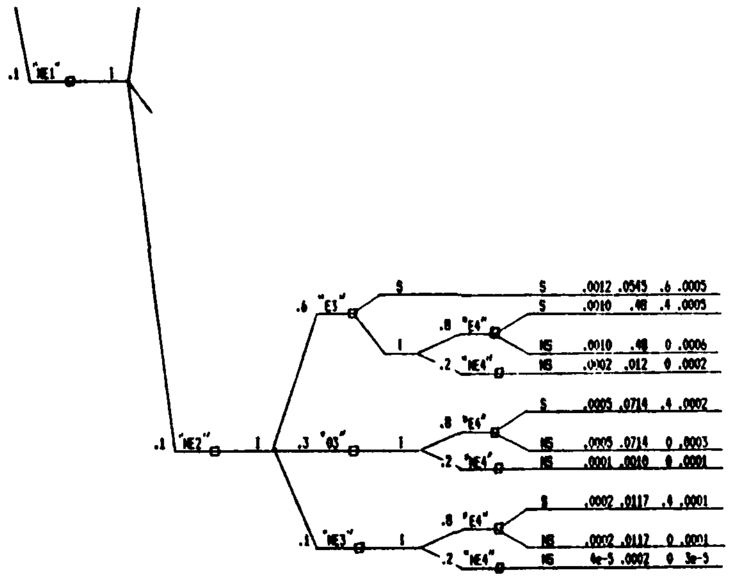
The U.S. Air Force has already fielded fighter aircraft capable of ID with more than one system. The systems modeled here, in conjunction with indirect ID, and procedural ID when necessary, can provide more than enough ID surety for beyond visual range employment. Pilots in some of these aircraft may be constrained unnecessarily. The data presented here clearly shows the cost of that constraint. Actual fighter ID systems should be simulated with more robust simulation techniques to validate this data and develop aircraft specific rules of engagement.

This model does not capture any of the dynamics of force-on-force simulations. The factors, such as correlation windows, which cause the two categories of errors can be estimated for each type of ID system. Force-on-force simulations could further investigate the incidence of these correlation alignment problems and provide accurate, rather than assumed, Type I and II errors of systems. Those simulations should concentrate on accurate modeling of the Type II errors, since those are most sensitive. The actual penalties involved in delays waiting for multiple ID confirmation should also be studied in force-on-force and man-in-the-loop simulation. Once better data is available, decision rules which approximate the "optimum" criteria can be developed for most aircraft and mission combinations.

APPENDIX A



A1



Decision Tree for ID Problem (cont)

A2

APPENDIX B

VARIABLE SETTINGS FOR SENSITIVITY INVESTIGATIONS

FIGURE	CASE	P(E)	PKb PKr	P(1st shot)	P("U"|E) P("U"|$\overline{E}$)	P("E2"/"02"|E) P("E2"/"02"|$\overline{E}$)	P("E4"|E) P("E4"|$\overline{E}$)
7 19	baseline	.8	.7 .6	1/.8/.6/.4	.9 .2	.6/.3 .05/.3	.8 .05
8	improved IFF	*	*	*	.95 .05	*	*
9	degraded NCTR	* *	* *	* *	* *	.5/.4 .1/.3	*
10	improved NCTR	*	*	*	*	.8/.15 .05/.15	*
11	large Type I	*	*	1/1/.8/.4	.8 *	.5/.3 *	*
12 15	mid Type I&II	*	*	1/1/.8/.4	*	*	*
13	small Type I	*	*	1/1/.8/.4	.98 *	.68/.3 *	*
14	large Type II	*	*	1/1/.8/.4	* .3	* .15/.3	*
16	small Type II	*	*	1/1/.8/.4	* .02	* .02/.3	*
17	low P(E)	.2	*	*	*	*	*
18	mid P(E)	.5	*	*	*	*	*

* same as baseline case

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GLOSSARY

AWACS	Airborne Warning and Control System
COMAAFCE	Commander, Allied Air Forces Central Europe (NATO)
COMFOURATAF	Commander, Fourth Allied Tactical Air Force (NATO)
EID	Electronic Identification
ID	Identification
IFF	Identification Friend or Foe
IFFN	Identification, Friend Foe or Neutral
IFFNJTF	Identification, Friend Foe or Neutral Joint Task Force
MK XII	Mark Twelve IFF system: Currently in use on all U.S. and some NATO aircraft.
MK XV	Mark Fifteen IFF System: NATO standard IFF of the future
NATO	North Atlantic Treaty Organization
NCTR	Non-Cooperative Target Recognition
NS	Not Shoot: used in the decision tree illustration to denote a decision to ID further before shooting.
PKb	Probability of Kill for the 'blue' missile
PKr	Probability of Kill for the 'red' missile
S	Shoot: used in the decision tree illustration to denote a decision to shoot.
SAM	Surface-to-Air Missile
SUPLAN	Suporting Plan
VID	Visual ID